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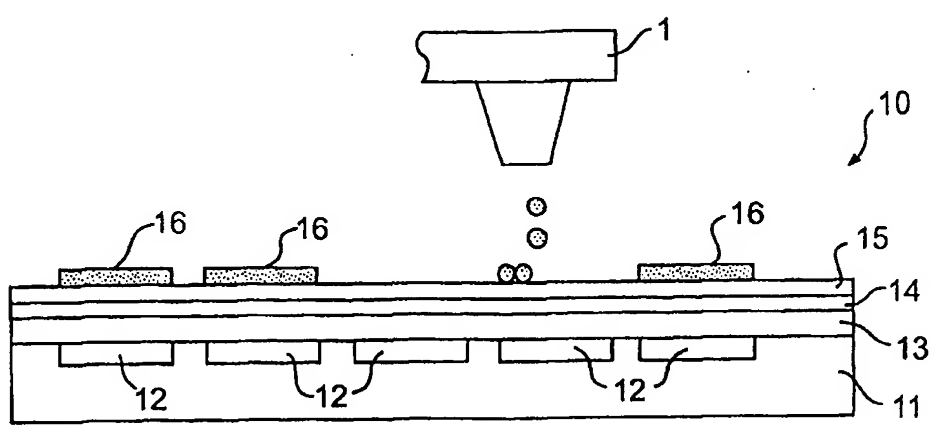

(57) Abstract

The present invention is directed to a method of manufacturing a full color organic light emitting diode display. The method includes the steps of providing an organic light emitting diode display (10), providing a protective layer (15) for the organic light emitting diode display (10), and selectively applying at least one color conversion material (16) on the protective layer (15). The color conversion material is applied using an ink jet printer (1).

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FULL COLOR ORGANIC LIGHT EMITTING DIODE DISPLAY AND METHOD FOR MAKING THE SAME USING INKJET FABRICATION

CROSS REFERENCE TO RELATED APPLICATIONS

This application relates to and claims priority on U.S. Provisional Application No. 60/098,535, filed August 28, 1998.

FIELD OF INVENTION

The present invention relates to a full color organic light emitting diode ("OLED") display and method for making the same whereby ink jet technology is employed to pattern color conversion materials used in conjunction with OLEDs to produce a full color display.

BACKGROUND OF THE INVENTION

OLEDs have been known for approximately two decades. All OLEDs work on the same general principles. One or more layers of semiconducting organic material is sandwiched between two electrodes. An electric current is applied to the device, causing negatively charged electrons to move into the organic material(s) from the cathode. Positive charge, typically referred to as holes, moves in the anode. The positive and negative charges meet in the center layers (i.e., the semiconducting organic material), combine, and produce photons. The wave-length -- and consequently the color -- of the photons depends on the electronic properties of the organic material in which the photons are generated.

Light emitting devices, which may be generally classified as organic or inorganic, are well known in the graphic display and imaging art. Among the benefits of organic light emitting devices are high visibility due to self-emission, as well as superior impact resistance, and ease of handling of the solid state devices. Organic light emitting devices may have practical application for television and graphic displays, as well as in digital printing applications.

An organic light emitting device is typically a laminate formed on a substrate such as soda-lime glass. A light-emitting layer of a luminescent organic solid, as well as adjacent semiconductor layers, are sandwiched between a cathode and an anode. The semiconductor layers may be hole-injecting and electron-injecting layers. The light-emitting layer may be any of a multitude of fluorescent organic solids.

When a potential difference is applied across the cathode and anode, electrons from the electron-injecting layer, and holes from the hole-injecting layer are injected into the light-emitting layer. They recombine, emitting light.

In a typical matrix-addressed OLED, numerous light emitting devices are formed on a single substrate and arranged in groups in a regular grid pattern. Several light emitting device groups forming a column of the grid may share a common cathode, or cathode line. Several light emitting device groups forming a row of the grid may share a common anode, or anode line. The individual light emitting devices in a given group emit light when their cathode line and anode line are activated at the same time. Activation may be by rows and columns or in an active matrix with individual cathode and anode pads.

Organic light emitting devices have a number of beneficial characteristics. These include a low activation voltage (about 4.5 volts), fast response when formed with a thin light-emitting layer, and high brightness in proportion to the injected electric current. By changing the kinds of flourescent organic solids making up the light-emitting layer, many different colors of light may be emitted, ranging from visible blue, to green, yellow, and red. Organic light emitting devices are currently the subject of aggressive investigative efforts.

The color of light emitted from the OLED device can be controlled by the selection of the organic material. White light is produced by generating blue, red and green lights simultaneously. Specifically, the precisely color of light emitted by a particular structure can be controlled both by selection of the organic material, as well as by selection of dopants. The formation of conventional color displays is typically more complex and expensive than the formation of monochrome displays.

An OLED is typically a thin film structure formed on a substrate such as silicon. A light emitting layer of a luminescent organic solid, as well as adjacent semiconductor layers, are sandwiched between a cathode and an anode. The semiconductor layers may be either hole-injecting or electron-injecting layers. The light emitting layer may be selected from any of a multitude of fluorescent organic solids. The light emitting layer may consist of multiple sublayers.

When a potential difference is applied across the device, negatively charged electrons move from the cathode to the electron-injecting layer and finally into the layer(s) of organic material. At the same time, positive charges, typically referred to as holes, move from the

anode to the hole-injection layer and finally into the same light emitting organic layer. When the positive and negative charges meet in the organic material layer(s), they recombine and produce photons. The wave length -- and consequently the color -- of the photons depends on the electronic properties of the organic material in which the photons are generated.

In a typical matrix-addressed OLED display, numerous OLEDs are formed on a single substrate and arranged in groups in a grid pattern. Several OLED groups forming a column of the grid may share a common cathode, or cathode line. Several OLED groups forming a row of the grid may share a common anode, or anode line. The individual OLEDs in a given group emit light when their cathode line and anode line are activated at the same time.

OLEDs have a number of beneficial characteristics. These characteristics include a low activation voltage (about 2 volts), fast response when formed with a thin light emitting layer, and high brightness in proportion to the injected electric current. Depending on the composition of the organic material making up the light emitting layer, many different colors of light may be produced, ranging from visible blue, to green, yellow and red.

It is difficult to pattern color conversion materials on top of an existing OLED structure, because conventional subtractive lithography will be harmful to the underlying OLED device. Also, it is difficult to etch one color converter off another.

As such, other means of applying and patterning color changing materials are being pursued, both onto a OLED and onto a separate glass plate.

The concept of patterning color filters for liquid crystal displays using ink jets is known. This concept, however, has not been commercialized. Others have attempted to pattern polymer emitting materials using ink jets. Thus, however, is extremely difficult because of the sensitivity of emitter materials. Still others have attempted a different approach to patterning color conversion materials on top of blue OLEDs using evaporation.

The prior art focused on patterning color filters, which can be easy and on patterning polymer emitters which can be very difficult. The patterning of color conversion materials should be intermediate in its difficulty.

OBJECTS OF THE INVENTION

It is an object of the present invention to provide a full color OLED device.

It is another object of the present invention to provide a OLED device with color conversion materials to produce a full color OLED device.

It is another object of the present invention to provide a OLED device with color conversion materials patterned on the OLED device using ink jets to produce a full color OLED device.

It is another object of the present invention to provide a blue light emitting OLED device with color conversion materials to produce a full color OLED device.

It is another object of the present invention to provide a blue light emitting OLED device with color conversion materials patterned on the blue light emitting OLED to produce a full color OLED device.

It is yet another object of the present invention to provide a simple process for producing a full color OLED display.

It is another object of the present invention to produce a full color OLED device with color conversion materials patterned or a transparent substrate located in close proximity to OLED device.

SUMMARY OF THE INVENTION

The present invention is directed to a method of manufacturing a full color organic light emitting diode display. The method includes the steps of providing an organic light emitting diode display, providing a protective layer for the organic light emitting diode display, and selectively applying at least one color conversion material on the protective layer. The protective layer is applied using an ink jet printer.

In one embodiment of the present invention, the step of providing a protective layer for the organic light emitting diode display includes the step of forming a protective layer on a top electrode of the organic light emitting diode display. In another embodiment of the present invention, the step of providing a protective layer for the organic light emitting diode display includes the step of positioning a protective substrate adjacent a top electrode of the organic light emitting diode display.

In accordance with the present invention, the at least one color conversion material is applied on the protective layer in a pattern that corresponds with the location of the electrodes in the organic light emitting diode display.

In accordance with the present invention, the at least one color conversion material may include a conjugated polymer. The at least one color conversion material may include a dye in a polymer matrix.

The present invention is also directed to a method of manufacturing a full color organic light emitting diode display. The method includes the steps of providing a transparent substrate, selectively applying at least one color conversion material on the transparent substrate using an ink jet printer, forming a protective layer on the transparent substrate and the at least one color conversion material, and forming an organic light emitting diode display on the protective layer.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention will now be described in conjunction with the following drawings in which like reference numerals designate like elements and wherein:

Fig. 1 is a schematic view illustrating a method of forming a full color OLED device according to one embodiment of the present invention;

Fig. 2 is a schematic view of a full color OLED device according to another embodiment of the present invention; and

Fig. 3 is a schematic view of a full color OLED device according to yet another embodiment of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

A preferred embodiment of the present invention is illustrated in Fig. 1. The full color OLED display **10** includes a substrate **11**. The substrate **11** is preferably formed from an opaque material because the OLED display **10** is an upwardly emitting device. An active matrix addressing system having electrodes **12** is formed in the opaque substrate **11**. A stack of organic layers **13** is formed on the substrate 11 and active matrix addressing system **12**. The stack of organic layers **13** preferably form a blue light emitting OLED. A transparent top electrode **14** is formed on the stack of organic layers **13**.

A protective layer **15** is formed on top of the transparent electrode 14 which is transparent and impervious to moisture and/or organic solvents. Onto the layer **15**, color conversion materials capable of converting blue light into green or red light are disposed in a pixel pattern **16**. The pixel pattern **16** is in alignment with a pattern of electrodes **12** in the substrate **11**. This is accomplished by using a precision ink jet printer **1**, which is capable

of placing small dots of liquid with great accuracy. Just as ink jet color printers can put down different inks in a pattern, the red and green color conversion materials can be applied to the protective layer **15** of the OLED **10** to produce a full color OLED device.

The ink jet printer **1** can place dot or stripe patterns as small as 5 μm. These patterns can be placed with 1-2 μm accuracy. Color conversion materials, which might consist of a single conjugated polymer or a dye in a polymer matrix, are dissolved in an appropriate solvent such that the solution has the required rheological characteristics for ink jet use. That is, not every liquid can be dispensed efficiently and accurately with an ink jet. With the proper formulations the materials can be patterned onto even very high resolution display arrays, (e.g., head mounted displays). The ink jet printer **1** places the color conversion material only where it is needed. Thus, it is unnecessary to etch excess material. This method would be economical, ~~including being very economical in the use of materials,~~ and would present fewer difficulties than alternative methods of preparing such an aligned array of conversion materials.

A variation of the full color display **10** of Fig. 1 is illustrated in Fig. 2. Like the full color OLED display **10**, the full color OLED display **20** includes a substrate **21**. The substrate **21** is preferably formed from an opaque material because the OLED display **20** is an upwardly emitting device. An active matrix addressing system having electrodes **22** is formed in the opaque substrate **21**. A stack of organic layers **23** is formed on the substrate **21** and active matrix addressing system **22**. The stack of engine layers **23** preferably form a blue light emitting OLED. A transparent top electrode **24** is formed on the stack of organic layers **23**.

A transparent protective layer may be formed on top of the transparent electrode **24**, as described above in connection with the OLED display **10**. Color conversion materials are patterned on a transparent substrate **25** forming a pixel pattern **26**. The pixel pattern **26** is in alignment with the electrodes **22** in the substrate **21**. The transparent substrate **25** may be positioned such that the pixel pattern **26** of the color conversion materials is adjacent and in close proximity to the top electrode **24**, as shown in Fig. 4. Alternatively, adjacent the top electrode **24**.

Another embodiment of the present invention is illustrated in Fig. 3. The full color OLED display **30** includes a transparent substrate **31**. At least one color conversion material

is patterned on the substrate **31** using the ink jet printer to form a plurality of color converters **32**. The color converters **32** are capable of changing the color of light produced by the OLED display **30** (e.g., blue light to green light and blue light to red light).

A protective layer **33** covers the color converters **32** and the transparent substrate **31**. The protective layer **33** is preferably formed from a transparent material. A transparent electrode **34** is formed on the protective layer **33**. A stack of organic layers **35** is formed on the transparent electrode. The stack of organic layers **35** preferably form a blue light emitting OLED. A top electrode **36** is formed on the stack of organic layers **35**. The top electrode **36** may be formed from an opaque material. In this embodiment, light is emitted downwardly through the transparent substrate **31**.

While this invention has been described in conjunction with specific embodiments thereof, it is evident that many alternatives, modifications and variations will be apparent to those skilled in the art. Accordingly, the preferred embodiments of the invention as set forth herein are intended to be illustrative, not limiting. Various changes may be made without departing from the spirit and scope of the invention as defined in the following claims.

WHAT IS CLAIMED IS:

1. A method of manufacturing a full color organic light emitting diode display, said method comprising the steps of:

providing an organic light emitting diode display;

providing a protective layer for said organic light emitting diode display; and

selectively applying at least one color conversion material on said protective layer using an ink jet printer.

2. The method according to Claim 1, wherein said step of providing a protective layer for said organic light emitting diode display includes the step of forming a protective layer on a top electrode of said organic light emitting diode display.

3. The method according to Claim 1, wherein said step of providing a protective layer for said organic light emitting diode display includes the step of positioning a protective substrate adjacent a top electrode of said organic light emitting diode display.

4. The method according to Claim 1, wherein said organic light emitting diode display includes a pattern of bottom electrodes located adjacent a substrate upon which said organic light emitting diode display is formed, wherein said step of selectively applying at least one color conversion material on said protective layer includes applying the at least one color conversion material to produce a color conversion pattern that is aligned with said pattern of bottom electrodes.

5. The method according to Claim 1, wherein said at least one color conversion material includes a conjugated polymer.

6. The method according to Claim 1, wherein said at least one color conversion material includes a dye in a polymer matrix.

7. A method of manufacturing a full color organic light emitting diode display, said method comprising the steps of:

providing a transparent substrate;

selectively applying at least one color conversion material on said transparent substrate using an ink jet printer;

forming a protective layer on said transparent substrate and said at least one color conversion material; and

forming an organic light emitting diode display on said protective layer.

8. The method according to Claim 7, wherein said at least one color conversion material includes a conjugated polymer.

9. The method according to Claim 7, wherein said at least one color conversion material includes a dye in a polymer matrix.

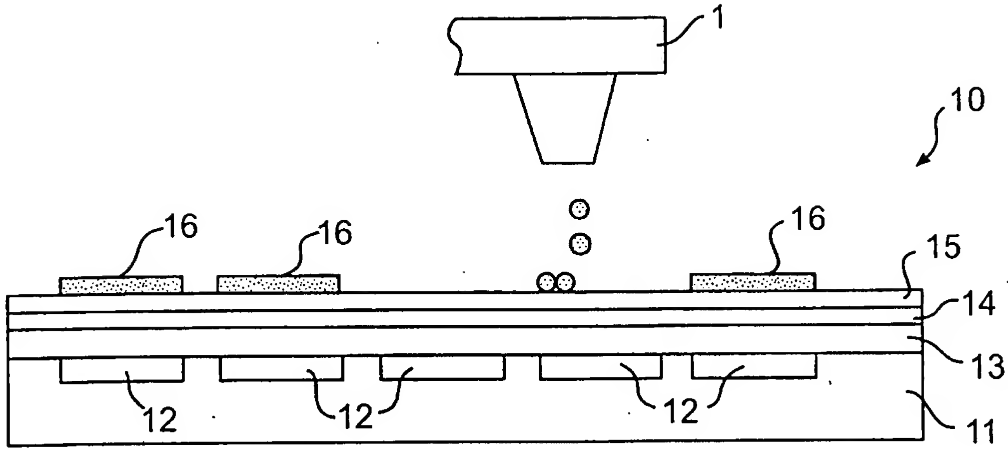

FIG. 1

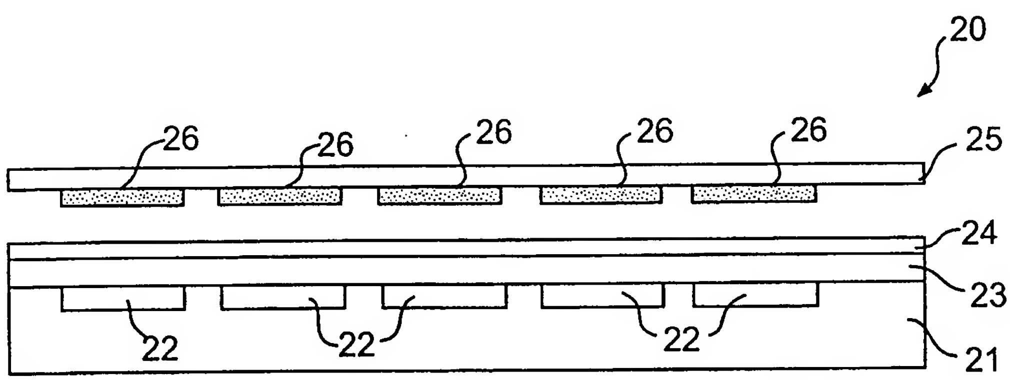

FIG. 2

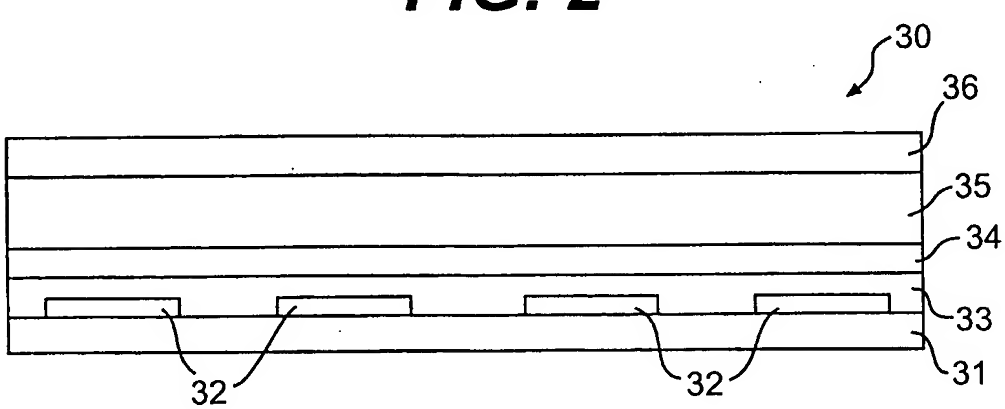

FIG. 3

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US99/19549

A. CLASSIFICATION OF SUBJECT MATTER
IPC(6) :Please See Extra Sheet.
US CL :Please See Extra Sheet.
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 156/277; 427/64, 66, 69; 428/209, 212, 457, 690, 917; 257/40, 98, 99, 103; 362/31, 320, 496, 511, 543

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
STN
search terms: organic light emitting diode?, oled?, led?, light emitting diode?, color?, print?, inkjet?, ink jet?, color filter?

C. ~~DOCUMENTS CONSIDERED TO BE RELEVANT~~

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y,P	US 5,920,080A (JONES) 06 July 1999, see entire document especially col. 3, lines 50-65; col. 10, lines 57-67; and col. 11, lines 1-17.	1-9
Y,P	US 5,895,115A (PARKER et al) 20 April 1999, see entire document especially col. 2, lines 39-67; col. 5, lines 10-23; col. 5, lines 39-53; and col. 6, lines 17-52.	1-9
A	US 5,798,170A (ZHANG et al) 25 August 1998, see entire document.	1-9
A	US 5,688,551A (LITTMAN et al) 18 November 1997, see entire document.	1-9

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

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INTERNATIONAL SEARCH REPORT

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A. CLASSIFICATION OF SUBJECT MATTER:
IPC (6):

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A. CLASSIFICATION OF SUBJECT MATTER:
US CL :

156/277; 427/64, 66, 69; 428/209, 212, 457, 690, 917; 257/40, 98, 99, 103; 362/31, 320, 496, 511, 543